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COMMISSION ON ATOMIC WEIGHTS

ATOMIC WEIGHTS OF THE ELEMENTS 1975

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Abstract—The biennial review of atomic weight determinations and other cognate data has resulted in the following changes in recommended values (1973 values in parentheses): F 18.998403 (18.99840); Si 28.0855* (28.086*); K. 39.0983* (39.098*); Mo 95.94 (95.94*); Cd 112.41 (112.40); Ba 137.33 (137.34*). These values are considered to be reliable to ±1 in the last digit, or ±3 when followed by an asterisk (*) and are incorporated in the full Table of Atomic Weights of the Elements 1975. Important changes in annotations and the wording of footnotes to the Table are discussed. The Report outlines various problems which arise from the present imprecise definition of "atomic weight (relative atomic mass)" and makes tentative proposals to ameliorate the difficulties. The concept of a defined "standard atomic weight" is introduced and the advantages of its tabulation for chemists are outlined. The importance of having informative labels on commercially available chemicals is emphasized, particularly in order to warn or reassure users of the presence or absence of materials containing elements with unusual atomic weights due to the enrichment or depletion of isotopes. The Report includes for the first time a complete review of the natural isotopic composition of the elements and also tabulates the Relative Atomic Masses for Selected Radioisotopes.

INTRODUCTION

The Commission on Atomic Weights met under the chairmanship of Professor N. N. Greenwood on 3–6 September, 1975, during the XXVIIIth IUPAC Conference in Madrid. Work done by the Commission members during the preceding two years in assessing atomic weights and other cognate data was reviewed and, as a result, the recommended values for the atomic weights of six elements were changed. The new values were immediately disseminated through an IUPAC News Release. The justifications for these changes are set out in the next Section and this is followed by the definitive Table of Atomic Weights of the Elements, 1975.

The Commission has for several years stressed the problems arising from the potential or actual variability of the atomic weights of many elements. Various footnotes to the tabulated values have been devised to alert readers to these problems and, in the section of this Report on the new Table of Atomic Weights, changes in the philosophy behind these footnotes are discussed and the new evidence which necessitates the use of such annotations for several additional elements is reviewed. General problems of terminology are also discussed in a separate section, and tentative proposals are advanced for a new definition of "atomic weight (relative atomic mass)". It is hoped that this will remove various operational difficulties which at present face the Commission in preparing its recommendations for *the* atomic weights of the elements, and should place the whole concept of *an* atomic weight on a sounder basis.

An increasing number of commercially available materials contain elements whose isotopic composition has been altered, either intentionally or inadvertently, from that of the element in nature. This problem afflicts some elements more than others and the Committee has been active in seeking to alert both manufacturers and suppliers to the need for appropriate phrases on labels. Suggestions are made for such explanatory statements which, in many cases, may well add to the value of the products described.

The results so far achieved by a working group, set up to assess the extensive body of mass-spectrometric data at present available on the natural isotopic abundances of the elements, are then summarized. This group has now been constituted as a Subcommittee for the Assessment of Isotopic Composition. This particularly important innovation will, in due course, enable the Commission to to publish a completely self-consistent set of isotopic compositions and atomic weights of the elements incorporating not only mass-spectrometric data but also results obtained from all other relevant methods. The present Report tabulates the range of published mass-spectrometrically determined isotopic abundances for each of the naturally occurring elements, together with the result of what is considered to be the best mass-spectrometric measurement (which is not necessarily a very good one in terms of 1975 techniques and knowledge) for a single natural source of each element, and an interim value for the isotopic composition for average properties. In future years the definitive self-consistent tabulation of isotopic compositions will also include the precise relative atomic mass of each nuclide and this will obviate the need for their separate tabulation. As an interim measure, however, the present Report continues the practice of tabulating the relative atomic mass of selected nuclides, but restricts these to certain nuclides of radioactive elements, including those such as technetium, promethium, and the heaviest elements, for which the Table of Atomic Weights lists only the atomic mass number in parentheses.

CHANGES IN ATOMIC WEIGHT VALUES

Fluorine

The only known stable nuclide with atomic number 9 is ^{19}F. The existence of other unrecognized stable isotopes of fluorine even in very small proportions is deemed unlikely. As in previous years the Commission, therefore, feels justified now in quoting the atomic weight of fluorine with a precision very close to that of the relative nuclidic mass of ^{19}F. The value given in the 1973 Table of Atomic Weights[1] is $A_r(F) = 18.99840$. It implies a confidence of about half a part per million. This uncertainty is far

†*Titular Members*: E. Roth, Chairman (France), N. E. Holden Secretary (USA), I. L. Barnes (USA), P. de Bièvre (Belgium), W. H. Johnson (USA), R. L. Martin (Australia), H. G. Thode (Canada), A. H. Wapstra (Netherlands); *Associate Members*: A. E. Cameron (USA), S. Fujiwara (Japan), N. N. Greenwood, past Chairman (UK), R. Hagemann (France), H. S. Peiser, Past Secretary (USA), N. Saito (Japan).

smaller than would be of likely concern to any chemist. It might, therefore, be argued that any further refinement of $A_r(^{19}F)$ could be of no relevance to the Commission's recommended value for $A_r(F)$. However, this conclusion is contrary to the Commission's basic policy of publishing values at the greatest precision which can be defended from an analysis of the published literature. Smith and Wapstra[2] have in 1975 published a value for $A_r(^{19}F)$ with an estimated uncertainty of only about 3 in 10^9. The Commission believes that the worst effect of an undiscovered isotope coupled with any reasonable interpretation of the Smith and Wapstra measurement now justifies a confidence of half a part in 10^7 for $A_r(F)$. As a result, the Commission now recommends $A_r(F) = 18.998403$. This value is consistent with, though more precise than, the value recommended by the Commission in its 1973 Table ($A_r(F) = 18.99840$), based on that from Wapstra and Gove[3] $A_r(^{19}F) = 18.9984046 \pm 7$. The value of $A_r(F) = 18.998403$ in the present Table of Atomic Weights is the most precisely stated atomic weight in any IUPAC Table of Atomic Weights. In the 1973 Table $A_r(P)$ was the most precisely quoted atomic weight of any non-radioactive element, and $A_r(Al)$, $A_r(Na)$, $A_r(Au)$ and $A_r(Bi)$ were also more precisely given at that time than $A_r(F)$.

Silicon

In 1961, the review of the Commission on Atomic Weights led to the atomic weight $A_r(Si) = 28.086 \pm 0.001$.[4] The interval of ±0.001 was intended to encompass a reported variability in isotopic composition of "normal" natural materials.[5] When in 1969 the Commission reviewed the uncertainties[6] members saw that value for $A_r(Si)$ was an average of independent mass-spectrometric determinations with a range somewhat greater than ±0.001. Altogether seven mass-spectrometric and three purely chemical determinations were under consideration at that time. Since the literature is not fully listed in the 1961 Report it is here given.[7–17] In addition to these, reference should be made to R. F. Hibbs' determination recorded in a 1949 report of the U.S. Atomic Energy Commission (AECU-556). The uncertainty assigned in the 1969 Report was ±0.003 the next larger value (to ±0.001) which is available by the conventional representation in the Table of Atomic Weights.

Barnes *et al.*[18] have recently obtained the isotopic abundance ratios for natural samples of silicon using electron-impact mass spectrometry, instrument-calibration procedures with nearly pure separated isotopes, and very careful chemical techniques for purification and analysis. A value for $A_r(Si) = 28.085526 \pm 0.000056$ was obtained for that sample based upon careful evaluation of systematic and random errors.

Reported natural variations of the abundance ratio of $^{28}Si/^{30}Si$ of 1.4%[5] are in conflict with the results obtained by Reynolds and Verhoogen.[19] Tilles[20] from analyzing a wider range of silicon samples resolved the discrepancy in favor of a maximum natural range of 0.53% in abundance ratios corresponding to a range of $A_r(Si)$ about a mean atomic weight value of ±0.00016. Remembering that the range may well be smaller, but that the sample here examined may not correspond to the mid-range value, the Commission on Atomic Weights now recommends $A_r(Si) = 28.0855 \pm 0.0003$, that is 28.0855*.

An indication of the Commission's judgment that Tilles' value for the natural variability of $A_r(Si)$ may be very much smaller than its upper bound is contained in the Commission's decision not to annotate that atomic weight with footnote "w" (see page 79). In other words, the Commission believes that there is no valid evidence that $A_r(Si)$ varies in its natural terrestrial occurrence by as much as ±0.0001.

Potassium

The value of $A_r(K) = 39.102$ for the atomic weight of potassium was adopted by the Atomic Weights Commission in its 1961 Report[4] based on mass-spectrometric abundance data by Nier.[21] This value was near the upper range of the best chemical determinations. In its 1969 Report[6] the Atomic Weights Commission considered the uncertainty of the above value to be no greater than ±0.003. A new analysis of older chemical data[22] led the Commission in 1971[23] to assign more credence to chemical evidence for a lower value of $A_r(K)$ and adopted 39.098 ± 0.003. It should also be noted that in the interval between 1961 and 1971 five significant new mass-spectrometric determinations were published. All these determinations yielded values of $A_r(K) < 39.100$. These and previous literature references are given in ref. 24 and need not be relisted here.

Much more accurate solid-sample thermal-ionization mass-spectrometric work by Garner *et al.*[24] fully confirm the previous judgment. They prepared standard samples for calibration by mixing isotopically and chemically pure isotopes and report for a natural reference sample $A_r(K) = 39.098304 \pm 0.000058$ including sources of possible systematic errors. A mineralogical survey (contrary to previous claims in the literature) showed the absence of natural variations in $A_r(K)$ within the limits of error of the experiment. In that experiment, the error limits are larger than in that used for the reference sample. Thus there is an additional uncertainty for $A_r(K)$ due to the possibility of small variations below the present level of precision. This uncertainty is less than natural variations of $A_r(K)$ claimed in the literature. The Atomic Weights Commission with some caution, therefore, now recommends $A_r(K) = 39.0983 \pm 0.0003$. It should be noted that the annotation of footnote "w" does not apply to potassium because the Commission now discounts reported variations of $A_r(K)$ in natural terrestrial specimens.

Molybdenum

Since 1961 the Atomic Weights Commission has recommended a value of $A_r(Mo) = 95.94$ for the atomic weight of molybdenum[4] based on chemical determinations.[25] Early mass-spectrometric determinations from the abundances of the seven isotopes were less reliable. When, in 1969, the Commission assigned consistent uncertainties which could be inferred from the values as tabulated[6] the uncertainty of $A_r(Mo)$ was judged to be in the range 0.01–0.03, i.e. $A_r(Mo) = 95.94$*. Since that time Commission members have studied five more papers[26–30] dealing with improved mass-spectrometric determinations. Although they are judged by the Commission not to be of equal reliability, their results all fall in the range of 95.93–95.94 in close agreement with the chemical value.[25] Consequently the Atomic Weights Commission in 1975 concluded that the uncertainty of the value could now be placed in the range of 0.003–0.01. On the basis of the mass-spectrometric values alone $A_r(Mo) = 95.93$ would be favored. The reliability of the chemical determination by Hönigschmid and Wittmann,[25] however, is still regarded as at least comparable. The Commission thus found no basis for lowering the tabulated value for molybdenum

but the improved precision enables it to recommend A_r(Mo) = 95.94 without an asterisk.

Cadmium

The several atomic weight determinations for cadmium have been remarkably concordant. From 1925 A_r(Cd) was tabulated as 112.41 until in the 1961 Commission Report[4] the value was lowered to 112.40 on the ^{12}C scale although that Report acknowledged two abundance measurements[31,32] which were higher, yielding 112.42 and 112.43 respectively. However, determinations by mass spectrometry for cadmium with eight stable isotopes must be considered subject to unusually high experimental error. So the Commission in its 1969 Report[6] relied on the seven principal chemical determinations by the Hönigschmid and Baxter groups quoted in the 1961 Report.[4] These determinations averaged to 112.400 and all lay within the range 112.392–112.410. The Commission thus assigned an uncertainty of ±0.01 to the value of 112.40.[6] Rosman and de Laeter[33] have now published new isotopic abundances in eight terrestrial minerals determined by mass spectrometry using double spiking for correcting mass discrimination. Their value for A_r(Cd) is 112.4094 ± 0.0049. The Commission therefore no longer wishes to disregard the higher mass-spectrometric values. In this they are reinforced by another mass-spectrometric measurement[10] not mentioned in the 1961 Report.[4] The Commission at that time must have been aware of this additional paper and may have neglected it on an unrecorded quality judgment. The Commission now recommends A_r(Cd) = 112.41. Since Rosman and de Laeter found no measurable natural variations, and since the majority of the chemical and mass-spectrometric values agree within ±0.01, the Commission feels justified in not raising the estimated uncertainty.

Barium

The history of the atomic weight determinations for barium resembles that for cadmium. Both elements have a large number of stable isotopes and good mass-spectrometric work is now available that should not be ignored relative to the chemical determinations. In 1929 the value, of A_r(Ba) was given as 137.36 based on several chemical determinations by Hönigschmid and Sachtleben,[34] and in the 1961 Commission Report this was adjusted to the ^{12}C scale and lowered further to 137.34 in part based on early mass-spectrometric work. Later mass-spectrometric work has consistently confirmed an even lower value; see Umemoto[36] (137.332), Eugster, Tera and Wasserburg[37] (137.3269), and de Laeter and Date[38] (137.327 ± 0.005).

The Commission has re-assessed Richards' old chemical determination[35] to yield A_r(Ba) = 137.338 ± 0.051 and Hönigschmid's as 137.340 ± 0.029 in slight variance with the Commission's 1961 assessment[4] which favored an average of 137.347. The Commission thus now recommends A_r(Ba) = 137.33 ± 0.01 as the most reliable value.

THE TABLE OF ATOMIC WEIGHTS, 1975

The changes listed in the previous Section are incorporated in the 1975 Table of Atomic Weights. As has been customary, the Table is presented, firstly, in alphabetic order by English names of the elements and, secondly, in order of atomic numbers. This year, as in the past, the Commission considered carefully all significant experimental or interpretative evidence bearing on atomic weights. The fact that no change is recommended for a given element should not be held by itself to imply that a new published determination had been overlooked. A review of the literature is generally given in these reports only when a change is being made. For example, the Commission has found some evidence for recommending small changes in the atomic weights of Ga and Pd, but decided that at this time the evidence was not sufficiently compelling. The need for new and better atomic weight determinations is felt as forcibly as ever. The margin in precision between the best atomic weight determinations and that of routinely available analytical techniques is shrinking and has become inadequate also for such elements as Ti and Ge.

A general change in the 1975 Table which the Commission has been debating for some years concerns a general policy regarding the footnotes. In recent years footnotes a, b, and c have given the reasons why some atomic weights could be given to high precision. The Commission now feels that this brief indication of some of the factors which are involved in the complex process of assessing experimental and interpretative evidence is no longer needed. Accordingly these footnotes are discontinued in the 1975 Table. By contrast the old footnotes d, e, f, and g gave proper warnings to users without which either the tabulated values could mislead some users, or many values would have to be given to lower than useful precision for the sake of oddities of nature or technology.

The Commission will continue to review this situation. Time may come when individual annotations should be written for every atomic weight. However, alternative future policies are discussed in the section on Terminology. For the time being, and probably for some time to come, the Commission believes its purposes will be served by the following four footnotes to the Tables of Atomic Weights:

w Element for which known variations in isotopic composition in normal terrestrial material prevent a more precise atomic weight being given; A_r(E) values should be applicable to any "normal" material.

x Element for which geological specimens are known in which the element has an anomalous isotopic composition, such that the difference in atomic weight of the element in such specimens from that given in the Table may exceed considerably the implied uncertainty.

y Element for which substantial variations in A_r from the value given can occur in commercially available material because of inadvertent or undisclosed change of isotopic composition.

z Element for which the value of A_r is that of the radioisotope of longest half-life.

The former footnotes d, e, f and g have thus been rearranged and relettered **w**, **y**, **z** and **x** to avoid confusion with earlier Tables of Atomic Weights. The Commission has also made some significant changes in the wording. In particular, the footnote **x** (formerly g) now is specifically applicable to those elements for which geological specimens are known with significantly different atomic weights—an anomalous isotopic composition is a necessary but not a sufficient condition. Similarly footnote f of 1973 is not automatically transferable to footnote **z** of 1975, because of a change in wording.

Despite the possibly more restricted applicability of footnote **x** (than was appropriate for g in 1973), it has been

TABLE OF ATOMIC WEIGHTS 1975

(Scaled to the relative atomic mass, $A_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ given here apply to elements as they exist naturally on earth and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit or ±3 when followed by an asterisk*. Values in parentheses are used for certain radioactive elements whose atomic weights cannot be quoted precisely without knowledge of origin; the value given is the atomic mass number of the isotope of that element of longest known half life.

Alphabetical order in English

Name	Symbol	Atomic number	Atomic weight	Footnotes
Actinium	Ac	89	227.0278	z
Aluminium	Al	13	26.98154	
Americium	Am	95	(243)	
Antimony	Sb	51	121.75*	
Argon	Ar	18	39.948*	w, x
Arsenic	As	33	74.9216	
Astatine	At	85	(210)	
Barium	Ba	56	137.33	x
Berkelium	Bk	97	(247)	
Beryllium	Be	4	9.01218	
Bismuth	Bi	83	208.9804	
Boron	B	5	10.81	w, y
Bromine	Br	35	79.904	
Cadmium	Cd	48	112.41	x
Caesium	Cs	55	132.9054	
Calcium	Ca	20	40.08	x
Californium	Cf	98	(251)	
Carbon	C	6	12.011	w
Cerium	Ce	58	140.12	x
Chlorine	Cl	17	35.453	
Chromium	Cr	24	51.996	
Cobalt	Co	27	58.9332	
Copper	Cu	29	63.546*	w
Curium	Cm	96	(247)	
Dysprosium	Dy	66	162.50*	
Einsteinium	Es	99	(254)	
Erbium	Er	68	167.26*	
Europium	Eu	63	151.96	x
Fermium	Fm	100	(257)	
Fluorine	F	9	18.998403	
Francium	Fr	87	(223)	
Gadolinium	Gd	64	157.25*	x
Gallium	Ga	31	69.72	
Germanium	Ge	32	72.59*	
Gold	Au	79	196.9665	
Hafnium	Hf	72	178.49*	
Helium	He	2	4.00260	x
Holmium	Ho	67	164.9304	
Hydrogen	H	1	1.0079	w
Indium	In	49	114.82	x
Iodine	I	53	126.9045	
Iridium	Ir	77	192.22*	
Iron	Fe	26	55.847*	
Krypton	Kr	36	83.80	x, y
Lanthanum	La	57	138.9055*	x
Lawrencium	Lr	103	(260)	
Lead	Pb	82	207.2	w, x
Lithium	Li	3	6.941*	w, x, y
Lutetium	Lu	71	174.97	
Magnesium	Mg	12	24.305	x
Manganese	Mn	25	54.9380	
Mendelevium	Md	101	(258)	
Mercury	Hg	80	200.59*	

TABLE OF ATOMIC WEIGHTS 1975 (*Cont.*)

Alphabetical order in English

Name	Symbol	Atomic number	Atomic weight	Footnotes
Molybdenum	Mo	42	95.94	
Neodymium	Nd	60	144.24*	x
Neon	Ne	10	20.179*	y
Neptunium	Np	93	237.0482	z
Nickel	Ni	28	58.70	
Niobium	Nb	41	92.9064	
Nitrogen	N	7	14.0067	
Nobelium	No	102	(259)	
Osmium	Os	76	190.2	x
Oxygen	O	8	15.9994*	w
Palladium	Pd	46	106.4	x
Phosphorus	P	15	30.97376	
Platinum	Pt	78	195.09*	
Plutonium	Pu	94	(244)	
Polonium	Po	84	(209)	
Potassium	K	19	39.0983*	
Praseodymium	Pr	59	140.9077	
Promethium	Pm	61	(145)	
Protactinium	Pa	91	231.0359	z
Radium	Ra	88	226.0254	x, z
Radon	Rn	86	(222)	
Rhenium	Re	75	186.207	
Rhodium	Rh	45	102.9055	
Rubidium	Rb	37	85.4678*	x
Ruthenium	Ru	44	101.07*	x
Samarium	Sm	62	150.4	x
Scandium	Sc	21	44.9559	
Selenium	Se	34	78.96*	
Silicon	Si	14	28.0855*	
Silver	Ag	47	107.868	x
Sodium	Na	11	22.98977	
Strontium	Sr	38	87.62	x
Sulfur	S	16	32.06	w
Tantalum	Ta	73	180.9479*	
Technetium	Tc	43	(97)	
Tellurium	Te	52	127.60*	x
Terbium	Tb	65	158.9254	
Thallium	Tl	81	204.37*	
Thorium	Th	90	232.0381	x, z
Thulium	Tm	69	168.9342	
Tin	Sn	50	118.69*	
Titanium	Ti	22	47.90*	
Tungsten (Wolfram)	W	74	183.85*	
Uranium	U	92	238.029	x, y
Vanadium	V	23	50.9414*	
Xenon	Xe	54	131.30	x, y
Ytterbium	Yb	70	173.04*	
Yttrium	Y	39	88.9059	
Zinc	Zn	30	65.38	
Zirconium	Zr	40	91.22	x

w Element for which known variations in isotopic composition in normal terrestrial material prevent a more precise atomic weight being given; A_r(E) values should be applicable to any "normal" material.

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TABLE OF ATOMIC WEIGHTS 1975

(Scaled to the relative atomic mass $A_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ given here apply to elements as they exist naturally on earth and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit or ±3 when followed by an asterisk*. Values in parentheses are used for certain radioactive elements whose atomic weights cannot be quoted precisely without knowledge of origin; the value given is the atomic mass number of the isotope of that element of longest known half life.

Order of Atomic Number				
Atomic number	Name	Symbol	Atomic weight	Footnotes
1	Hydrogen	H	1.0079	w
2	Helium	He	4.00260	x
3	Lithium	Li	6.941*	w, x, y
4	Beryllium	Be	9.01218	
5	Boron	B	10.81	w, y
6	Carbon	C	12.011	w
7	Nitrogen	N	14.0067	
8	Oxygen	O	15.9994*	w
9	Fluorine	F	18.998403	
10	Neon	Ne	20.179*	y
11	Sodium	Na	22.98977	
12	Magnesium	Mg	24.305	x
13	Aluminium	Al	26.98154	
14	Silicon	Si	28.0855*	
15	Phosphorus	P	30.97376	
16	Sulfur	S	32.06	w
17	Chlorine	Cl	35.453	
18	Argon	Ar	39.948*	w, x
19	Potassium	K	39.0983*	
20	Calcium	Ca	40.08	x
21	Scandium	Sc	44.9559	
22	Titanium	Ti	47.90*	
23	Vanadium	V	50.9414*	
24	Chromium	Cr	51.996	
25	Maganese	Mn	54.9380	
26	Iron	Fe	55.847*	
27	Cobalt	Co	58.9332	
28	Nickel	Ni	58.70	
29	Copper	Cu	63.546*	w
30	Zinc	Zn	65.38	
31	Gallium	Ga	69.72	
32	Germanium	Ge	72.59*	
33	Arsenic	As	74.9216	
34	Selenium	Se	78.96*	
35	Bromine	Br	79.904	
36	Krypton	Kr	83.80	x, y
37	Rubidium	Rb	85.4678*	x
38	Strontium	Sr	87.62	x
39	Yttrium	Y	88.9059	
40	Zirconium	Zr	91.22	x
41	Niobium	Nb	92.9064	
42	Molybdenum	Mo	95.94	
43	Technetium	Tc	(97)	
44	Ruthenium	Ru	101.07*	x
45	Rhodium	Rh	102.9055	
46	Palladium	Pd	106.4	x
47	Silver	Ag	107.868	x
48	Cadmium	Cd	112.41	x
49	Indium	In	114.82	x
50	Tin	Sn	118.69*	
51	Antimony	Sb	121.75*	
52	Tellurium	Te	127.60*	x
53	Iodine	I	126.9045	

TABLE OF ATOMIC WEIGHTS 1975 (*Cont.*)

Order of AtomicNumber

Atomic number	Name	Symbol	Atomic weight	Footnotes
54	Xenon	Xe	131.30	x, y
55	Caesium	Cs	132.9054	
56	Barium	Ba	137.33	x
57	Lanthanum	La	138.9055*	x
58	Cerium	Ce	140.12	x
59	Praseodymium	Pr	140.9077	
60	Neodymium	Nd	144.24*	x
61	Promethium	Pm	(145)	
62	Samarium	Sm	150.4	x
63	Europium	Eu	151.96	x
64	Gadolinium	Gd	157.25*	x
65	Terbium	Tb	158.9254	
66	Dysprosium	Dy	162.50*	
67	Holmium	Ho	164.9304	
68	Erbium	Er	167.26*	
69	Thulium	Tm	168.9342	
70	Ytterbium	Yb	173.04*	
71	Lutetium	Lu	174.97	
72	Hafnium	Hf	178.49*	
73	Tantalum	Ta	180.9479*	
74	Wolfram (Tungsten)	W	183.85*	
75	Rhenium	Re	186.207	
76	Osmium	Os	190.2	x
77	Iridium	Ir	192.22*	
78	Platinum	Pt	195.09*	
79	Gold	Au	196.9665	
80	Mercury	Hg	200.59*	
81	Thallium	Tl	204.37*	
82	Lead	Pb	207.2	w, x
83	Bismuth	Bi	208.9804	
84	Polonium	Po	(209)	
85	Astatine	At	(210)	
86	Radon	Rn	(222)	
87	Francium	Fr	(223)	
88	Radium	Ra	226.0254	x, z
89	Actinium	Ac	227.0278	z
90	Thorium	Th	232.0381	x, z
91	Protactinium	Pa	231.0359	z
92	Uranium	U	238.029	x, y
93	Neptunium	Np	237.0482	z
94	Plutonium	Pu	(244)	
95	Americium	Am	(243)	
96	Curium	Cm	(247)	
97	Berkelium	Bk	(247)	
98	Californium	Cf	(251)	
99	Einstenium	Es	(254)	
100	Fermium	Fm	(257)	
101	Mendelevium	Md	(258)	
102	Nobelium	No	(259)	
103	Lawrencium	Lr	(260)	

w Element for which known variations in isotopic composition in normal terrestrial material prevent a more precise atomic weight being given; A_r(E) values should be applicable to any "normal" material.

x Element for which geological specimens are known in which the element has an anomalous isotopic composition, such that the difference in atomic weight of the element in such specimens from that given in the Table may exceed considerably the implied uncertainty.

y Element for which substantial variations in A_r from the value given can occur in commercially available material because of inadvertent or undisclosed change of isotopic composition.

z Element for which the value of A_r is that of the radioisotope of longest half-life.

added to a number of elements. Helium from beta decay of tritium, though very rare geologically, needs footnote x. Even more uncommon, a radioactive isotope of niobium, ^{92}Nb, has been detected in natural ores at concentrations of about one part in 10^{10}. Since ^{92}Nb decays by electron capture, traces of ^{92}Zr must occur in niobium ores of ancient origin. There is a second reason why Zr must now be given the footnote x. Further investigation of the natural nuclear chain reaction at the Oklo quarry in Gabon[1] has now confirmed the occurrence of anomalous Ag, Te, Ce;[39] Xe, Ru, Zr;[40] Nd, Sm, Gd, Ru, U;[41] and Nd, Sm, Eu, Gd, Kr, Xe, and Pd.[42] All these elements are now annotated with footnote x. However, Mo, Sn and Sb, are not given that annotation yet, because their discovery with anomalous composition at Oklo has not yet been published, although such occurrence can hardly be questioned.

After considerable discussion the Commission decided that actinium should be given footnote z (old f), and the relative atomic mass of the isotope with the longest half-life namely ^{227}Ac, be re-entered as 227.0278. There was some reluctance to reverse the close previous decision not to quote an atomic weight for actinium. Changes in the atomic weights Table should be for compelling reasons. The Commission felt that, in this instance, the advantage of greater consistency was sufficiently compelling.

The Commission was also well aware of the fact that a case could be made for withdrawing an atomic weight for neptunium with the footnote z. In some later year the Commission may well decide that ^{236}Np (in addition to ^{237}Np) might be found in a laboratory, but for the present, the value quoted for the atomic weight of neptunium is the relative isotopic mass of ^{237}Np, which is the most common isotope of this element.

There is a wide variation in the precision with which the atomic weights of the naturally occurring elements can be tabulated under the Commission's policy of recommending the greatest precision that can reasonably be supported by published measurements. In its 1971 Report[23] the Commission published a plot of relative uncertainties of the then atomic weights of all the elements with stable nuclides and a similar graph (see Fig. 1) is included in this Report. It now also indicates by arrowed lines the increase in reliability of several values newly recommended in 1973 and 1975. Another feature of the present graph is the use of a horizontal bar below a graph point to indicate when footnote w of the Table of Atomic Weights applies. Footnote w implies that the uncertainty in the quoted atomic weight value cannot be reduced unless previously credible published variability in nature is proved erroneous or unless "atomic weight" is redefined generally or for purposes of a more precise tabulation (see section on Terminology). It will be noted that, among elements shown with a bar are B, Pb, Li, and S, four of the ten elements with the least precisely stated atomic weights.

The IUPAC Commission on Atomic Weights has no direct responsibility for terms, definitions, spellings, *etc.* Nevertheless, the Commission's views are often sought both inside and outside IUPAC. The Commission actively supports IUPAC spelling, terminology, and definitions and is, therefore, particularly concerned at the continued widespread use of Lw instead of the IUPAC approved symbol Lr for lawrencium. It wishes to emphasize that Lr has been the internationally agreed and accepted symbol since 1963.

Under guidance of the Commission on Atomic Weights, a Table of Atomic Weights to Four Significant Figures has been prepared by the IUPAC Committee on Teaching of Chemistry in their "*International Newsletter on Chemical Education*".[43] This simplified Table may suit many practising chemists while also introducing teachers and students to the fact that atomic weights are not all constants of nature even at the precision of their concern.

TERMINOLOGY

Previous discussions by the Commission on Atomic Weights (see especially the 1973 Report[1]) have revealed various difficulties arising from the current definition of "atomic weight". These stem from the fact that, for some elements, there can be more than one atomic-weight value stated to the precision available with present experimental techniques. In some fields of modern chemistry and technology an operational problem therefore exists which can no longer be disregarded, since the best experimental techniques can give values for some elements which are more precise than the enforced uncertainties that result from the indeterminacy arising from the present definition of atomic weight. At the Madrid Conference the Commission was fortunate to receive the comments and

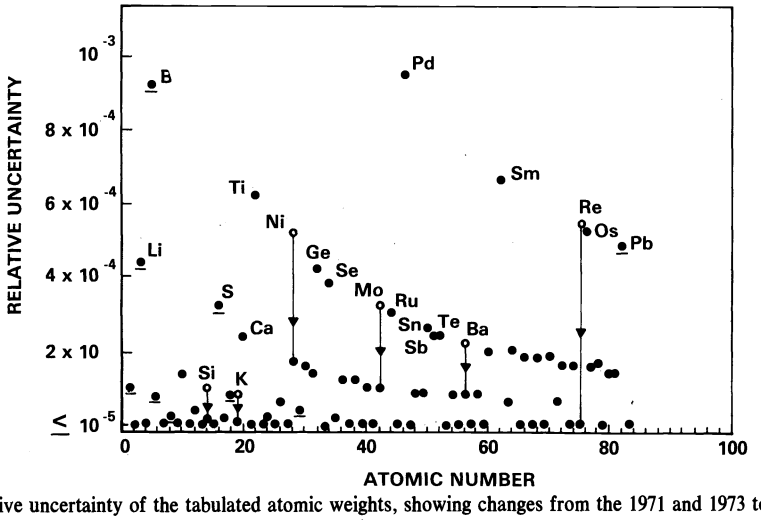

Fig. 1. Relative uncertainty of the tabulated atomic weights, showing changes from the 1971 and 1973 to the 1975 values.

advice from an Open Meeting conducted in cooperation with the IUPAC Inorganic Division, the Interdivisional Committee on Education and other IUPAC commissions concerned with terminology. The Commission on Atomic Weights noted the following consensus which emerged:

(1) There is an imprecision in the definition of "atomic weight".

(2) A new definition should depart as little as possible from the current definition.

(3) A new definition should describe the material concerned with appropriate precision, which in some instances might involve a statement on its isotopic composition.

(4) The Commission on Atomic Weights should suggest tentative changes of definition or rules in presenting the Atomic Weights Table so as to overcome the present lack of clarity. These tentative proposals should, if possible, be included in this 1975 Report so that the principles involved could be understood and discussed by interested persons or groups before the next IUPAC Conference, in 1977, when more definite proposals could be discussed by the appropriate IUPAC commissions.

Accordingly, the Commission on Atomic Weights has accepted temporarily the responsibility for providing a focus for the discussion on this definition although this Commission is not generally concerned with or responsible for definitions. In the belief that the discussion will be simplified by a set of concrete proposals the Commission now presents such proposals which, it is hoped, might form the basis of a consensus, if not unanimity. Uniqueness is not claimed for the solution proposed. Therefore, it would be helpful for comments to be of two types—either minor changes in wording of the definition or a justified preference for an alternative solution to the problem.

The latter type of comment could, but need not, be accompanied by a substitute wording. All comments should be sent to the Commission Secretary, Dr. N. E. Holden, Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

At present, atomic weight of an element is defined as "the ratio of the average mass per atom of a natural nuclidic composition of an element to 1/12 of the mass of an atom of nuclide ^{12}C." The basic choice is either to define more accurately "natural nuclidic composition" or to accept that the nuclidic composition covers a range for many elements so that there is not one naturally unique and experimentally accessible value for some of the elements.

The Commission recommends the latter alternative and proposes the following tentative definition:

An atomic weight of an element is "the ratio of the average mass per atom of an element to 1/12 of the mass of an atom of nuclide ^{12}C".

An alternative wording which retains the essential features of the definition is "the ratio of the mass of one mole of atoms of an element to 1/12 of the mass of one mole of nuclide ^{12}C".

There are several implications and consequences of this proposal:

(1) The new definition differs from the current one only by the omission of the phrase "of a natural nuclidic composition". Even the current definition does not claim uniqueness for "a natural nuclidic composition". This proposed omission, therefore, would eliminate the difficulty of defining "natural" (presumably terrestrial) as opposed to "artificially" altered compositions (including presumably such compositions as have been influenced by human intervention.)

(2) Another consequence of the omission is that an element in a sample of a separated or synthetic isotope can also be said to have an atomic weight. This effect the Commission considers desirable.

(3) The fact that atomic weights may not be unique is still not directly contained in the definition but is implied by stating that the definition is of *an* atomic weight rather than *the* atomic weight of an element.

(4) There was a consensus at the Madrid meeting that further refinement of the definition by specifying the electronic or nuclear ground states, rest mass, *etc.*, of the nuclides concerned was for the time being irrelevant and therefore undesirable for the present frame of chemical precision and nuclear industrial activity.

(5) The need for qualifying adjectives for the elements such as "non-radiogenic", "terrestrial", "normal" or "of natural nuclidic composition" would largely disappear. A formal definition would no longer be needed or appropriate to the Commission. However, when the use of such a term is involved, Commission members will probably tend to use "normal" in the sense of "terrestrial with isotopic composition unaltered in its geological past".

(6) The new definition does not solve the principal problem of the Commission namely how to present the most accurate available values for those who need to use them. The concept of accuracy implies the existence of a true value and the definition purposely denies the necessary existence of one true value for every element. In this connection it should be mentioned that, before the Madrid meeting, some Commission members had hoped that by appropriate refinement an operationally acceptable definition leading to unique atomic weight values could be agreed.

At the Madrid meeting it became clear that a consensus could not be reached on such a definition. Instead it would be easier to agree on a definition, such as that proposed above, which for some elements is of operationally adequate precision only when the material itself is precisely defined.

Under these circumstances, the Commission must choose one of the following possibilities for its published Table of Atomic Weights:

(1) to limit the precision of the tabulated values so that all atomic weight values are covered by the implied range;

(2) to select the tabulated values consistent with most commonly encountered materials by using a clearly stated convention;

(3) to increase the number of annotations some of which would have to be written for individual elements.

The Commission has a strong preference for the second alternative and is left to decide for each individual element how to determine the atomic weight value, to be called the Standard Atomic Weight, for entry into the Table of Atomic Weights. The following alternatives then present themselves identically for each element in turn or for all elements collectively:

(1) *An arbitrary number to be the "true" or "defined" atomic weight of the element.* Such numbers would be so chosen that, for commonly available materials, the difference between the atomic weight of any sample containing the element and the defined true value for that element would be minimized by some convention.

(2) *A similarly arbitrary isotopic composition.* Since the nuclidic masses are more accurately known than the atomic weight values needed by chemists, the defined

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY

The notes appended to some of the values are abbreviated as follows: "R" is appended when the range corresponds to that of known natural variations; "D" is appended wher range corresponds to differences between published values not supported by established natural variations; "U" is appended when the range falls within the uncertainties quote column 4; "G" is appended when the element is known to have a highly anomalous composition in certain, specific, geological specimens; "X" is appended when data from one measurement is available and any possible variations are not known.

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
1	H	1	99.9910–99.9835	R, G	99.984424	70HAG1	IAEA-SMOW	99.985
		2	0.0173–0.0090		0.015576		IAEA-SLAP	0.015
2	He	3	$0.002–5 \times 10^{-9}$		0.000137	70MAM1		0.00013
		4	100–99.998		99.999863			99.99987
3	Li	6	8.251–7.30	R, G	7.6809	73FLE1	SVEC	7.5
		7	92.61–91.749		92.3191			92.5
4	Be	9			100			100
5	B	10	20.2–19.8	R, G	19.824	69BIE1	NBS-SRM 951,	20
		11	80.2–79.8		80.176		EEC-GEEL	80
6	C	12	98.94–98.86	R, G	98.889	57CRA1	NBS-RS 20	98.89
		13	1.26–1.06		1.111			1.11
7	N	14		G	99.64	58JUN1	AIR	99.64
		15			0.36			0.36
8	O	16	99.810–99.7577	R, G	99.7587	50NIE1	NBS-RS 20	99.76
		17	0.0407–0.035		0.0374		IAEA-SMOW; SLAP	0.04
		18	0.2094–0.190		0.2039		NBS-RS-1 and 1a	0.20
9	F	19			100			100
10	Ne	20	90.91–89.99	U, G	90.514	66WAL1	AIR	90.51
		21	0.30–0.257		0.266			0.27
		22	9.72–8.82		9.220			9.22
11	Na	23			100			100
12	Mg	24		U	78.992	66CAT1	NBS-SRM 980	78.99
		25			10.003			10.00
		26			11.005			11.01
13	Al	27			100			100
14	Si	28	93.43–91.03	R, G	92.229	75BAR1	NBS-SRM 990	92.23
		29	4.73–4.60		4.670			4.67
		30	3.14–3.06		3.101			3.10
15	P	31			100			100
16	S	32	95.09–94.84	R, G	95.018	51MAC1		95.00
		33	0.76–0.74		0.750			0.76
		34	4.34–4.18		4.215			4.22
		36	0.017–0.0136		0.017			0.02
17	Cl	35		R	75.7705	62SHI2	NBS-SRM 975	75.77
		37			24.2295			24.23
18	Ar	36		G	0.339	71MEL1	AIR	0.34
		38			0.064			0.07
		40			99.597			99.59
19	K	39		R	93.25811	75GAR1	NBS-SRM 985	93.26
		40			0.01167			0.01
		41			6.73022			6.73
20	Ca	40		R, G	96.941	72MOO1	NBS-SRM 915	96.941
		42			0.647			0.647
		43			0.135			0.135
		44			2.086			2.086
		46			0.004			0.004
		48			0.187			0.187
21	Sc	45			100			100

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY (*cont.*)

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
22	Ti	46	8.24–7.99	R	8.24	68BEL1		8.0
		47	7.44–7.29		7.44			7.5
		48	73.99–73.71		73.71			73.7
		49	5.46–5.33		5.43			5.5
		50	5.35–5.18		5.18			5.3
23	V	50	0.2497–0.2444	R	0.2497	63SVE1		0.25
		51	99.756–99.750		99.7503			99.75
24	Cr	50	4.357–4.3452	R	4.3452	66SHI1	NBS-SRM 979	4.35
		52	83.7895–83.760		83.7895			83.79
		53	9.508–9.5006		9.5006			9.50
		54	2.375–2.3647		2.3647			2.36
25	Mn	55			100			100
26	Fe	54	6.04–5.81	D	5.900	49HIB2		5.8
		56	91.68–91.52		91.520			91.8
		57	2.245–2.11		2.245			2.1
		58	0.34–0.28		0.335			0.3
27	Co	59			100			100
28	Ni	58	68.274–67.76	R	68.274	73BAR1		68.27
		60	26.424–26.095		26.095			26.10
		61	1.25–1.134		1.134			1.13
		62	3.711–3.593		3.593			3.59
		64	1.16–0.904		0.904			0.91
29	Cu	63	69.24–68.98	R	69.174	64SHI1	NBS-SRM 976	69.2
		65	31.02–30.76		30.826			30.8
30	Zn	64		G	48.63	72ROS1		48.6
		66			27.90			27.9
		67			4.10			4.1
		68			18.75			18.8
		70			0.62			0.6
31	Ga	69	60.5–59.988	X	59.988	74LAE1		60
		71	40.012–39.5		40.012			40
32	Ge	70	21.11–20.38		20.52	53REY1		20.5
		72	27.67–27.37		27.43			27.4
		73	7.86–7.62		7.76			7.8
		74	36.65–36.09		36.53			36.5
		76	7.82–7.45		7.76			7.8
33	As	75			100			100
34	Se	74	0.96–0.88	R	0.88	48WHI1		0.9
		76	9.12–8.95		8.95			9.0
		77	7.65–7.50		7.65			7.6
		78	23.61–23.51		23.51			23.5
		80	49.96–49.62		49.62			49.8
		82	9.39–8.84		9.39			9.2
35	Br	79	50.686–50.51	R	50.686	64CAT1	NBS-SRM 977	50.69
		81	49.49–49.314		49.314			49.31
36	Kr	78	0.36–0.357	G	0.35	50SCH1	AIR	0.35
		80	2.29–2.223		2.29			2.25
		82	11.58–11.49		11.58			11.6
		83	11.55–11.44		11.51			11.5
		84	57.14–56.90		56.95			57.0
		86	17.44–17.24		17.31			17.3
37	Rb	85	72.60–72.14	G	72.1654	69CAT1	NBS-SRM 984	72.17
		87	27.86–27.40		27.8346			27.83
38	Sr	84	0.58–0.55	G	0.5572	73MOO1	NBS-SRM's 987, 988, 607	0.5
		86	9.99–9.75		9.8601			9.9
		87	7.14–6.94		7.0021			7.0
		88	82.75–82.29		82.5806			82.6

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY (*cont.*)

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
39	Y	89			100			100
40	Zr	90	51.7–51.12	D, G	51.46	48WHI1		51.4
		91	11.23–10.8		11.23			11.2
		92	17.4–17.1		17.11			17.1
		94	17.57–17.38		17.40			17.5
		96	2.9–2.79		2.80			2.8
41	Nb	93			100			100
42	Mo	92	15.05–14.74	D, G	14.8362	74MOO1		14.8
		94	9.35–9.11		9.2466			9.3
		95	15.93–15.78		15.9201			15.9
		96	16.71–16.56		16.6756			16.7
		97	9.6–9.48		9.5551			9.6
		98	24.42–24.00		24.1329			24.1
		100	9.63–9.60		9.6335			9.6
43	Tc							
44	Ru	96	5.57–5.46	D, G	5.57	56WHI1		5.5
		98	1.91–1.84		1.86			1.9
		99	12.77–12.7		12.7			12.7
		100	12.69–12.56		12.6			12.6
		101	17.1–17.01		17.1			17.1
		102	31.7–31.52		31.6			31.6
		104	18.67–18.5		18.5			18.6
45	Rh	103			100			100
46	Pd	102		D, G	0.96	53SIT1		1.0
		104	11.06–10.97		10.97			11.0
		105	22.23–21.82		22.23			22.2
		106	27.66–27.33		27.33			27.3
		108	27.24–26.71		26.71			26.7
		110	12.20–11.81		11.81			11.8
47	Ag	107			51.830	62SHI1	NBS-SRM 978	51.83
		109			48.170			48.17
48	Cd	106	1.22–1.21	D, G	1.215	48LEL1		1.2
		108	0.98–0.875		0.875			0.9
		110	12.39–12.35		12.39			12.4
		111	12.78–12.75		12.75			12.8
		112	24.2–24.07		24.07			24.0
		113	12.30–12.26		12.26			12.3
		114	28.86–28.75		28.86			28.8
		116	7.63–7.58		7.58			7.6
49	In	113	4.33–4.16	D	4.33	56WHI1		4.3
		115	95.84–95.67		95.67			95.7
50	Sn	112	1.017–0.90	D	1.011	67LAE1		1.0
		114	0.681–0.61		0.670			0.7
		115	0.376–0.33		0.376			0.4
		116	14.78–14.07		14.760			14.7
		117	7.767–7.51		7.746			7.7
		118	24.31–23.84		24.300			24.3
		119	8.62–8.45		8.555			8.6
		120	33.11–32.34		32.382			32.4
		122	4.559–4.78		4.559			4.6
		124	6.11–5.626		5.641			5.6
51	Sb	121		X	57.25	48WHI1		57.3
		123			42.75			42.7
52	Te	120	0.091–0.088	D, G	0.09	48WHI1		0.1
		122	2.49–2.43		2.49			2.5
		123	0.89–0.85		0.89			0.9
		124	4.74–4.59		4.63			4.6
		125	7.03–6.97		7.01			7.0
		126	18.72–18.70		18.72			18.7

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY (*cont.*)

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
		128	31.85–31.72		31.72			31.7
		130	34.51–34.27		34.45			34.5
53	I	127			100			100
54	Xe	124	0.102–0.095	D, G	0.09	50NIE2	AIR	0.1
		126	0.098–0.088		0.09			0.1
		128	1.93–1.91		1.92			1.9
		129	26.51–26.24		26.44			26.4
		130	4.08–3.68		4.08			4.1
		131	21.24–21.04		21.18			21.2
		132	27.12–26.88		26.89			26.9
		134	10.54–10.43		10.44			10.4
		136	8.98–8.87		8.87			8.9
55	Cs	133			100			100
56	Ba	130	0.106–0.098	D, G	0.106	69EUG1		0.1
		132	0.1017–0.091		0.101			0.1
		134	2.42–2.33		2.417			2.4
		135	6.605–6.42		6.592			6.6
		136	7.87–7.77		7.853			7.9
		137	11.32–11.13		11.232			11.2
		138	72.11–71.66		71.699			71.7
57	La	138		G, X	0.089	56WHI1		0.09
		139			99.911			99.91
58	Ce	136	0.195–0.190	D, G	0.190	62UME1		0.2
		138	0.265–0.250		0.254			0.3
		140	88.48–88.449		88.475			88.4
		142	11.098–11.07		11.081			11.1
59	Pr	141			100			100
60	Nd	142	27.3–26.80	D, G	27.157	74BAR1		27.2
		143	12.32–12.12		12.177			12.2
		144	23.97–23.795		23.795			23.8
		145	8.30–8.23		8.293			8.3
		146	17.35–17.06		17.188			17.2
		148	5.78–5.66		5.755			5.7
		150	5.69–5.53		5.635			5.6
61	Pm							
62	Sm	144	3.16–2.87	D, G	3.12	75LUG1		3.1
		147	15.098–14.87		15.10			15.1
		148	11.35–11.22		11.30			11.3
		149	13.96–13.82		13.86			13.9
		150	7.47–7.36		7.38			7.4
		152	26.90–26.55		26.65			26.6
		154	22.88–22.43		22.59			22.6
63	Eu	151	47.86–47.85	D, G	47.86	57COL1		47.8
		153	52.25–52.14		52.14			52.2
64	Gd	152	0.205–0.20	G	0.20	48HES1		0.2
		154	2.86–2.1		2.15			2.2
		155	15.61–14.68		14.78			14.8
		156	20.67–20.36		20.59			20.5
		157	16.42–15.64		15.71			15.7
		158	24.96–23.45		24.78			24.8
		160	22.01–20.87		21.79			21.8
65	Tb	159			100			100
66	Dy	156	0.064–0.0524	D, G	0.06	57COL1		0.06
		158	0.105–0.0902		0.10			0.1
		160	2.36–2.294		2.34			2.34
		161	19.0–18.73		19.0			18.9
		162	25.53–25.36		25.5			25.5
		163	24.97–24.9		24.9			24.9
		164	28.47–28.1		28.1			28.2

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY (*cont.*)

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
67	Ho	165			100			100
68	Er	162	0.154–0.136	D	0.14	50HAY1		0.1
		164	1.60–1.56		1.56			1.6
		166	33.41–33.36		33.41			33.4
		167	22.94–22.82		22.94			22.9
		168	27.07–27.02		27.07			27.0
		170	15.04–14.88		14.88			15.0
69	Tm	169			100			100
70	Yb	168	0.140–0.130	D	0.135	57COL1		0.1
		170	3.14–3.03		3.14			3.1
		171	14.4–14.27		14.4			14.3
		172	21.9–21.77		21.9			21.9
		173	16.2–16.08		16.2			16.2
		174	31.91–31.6		31.6			31.7
		176	12.80–12.6		12.6			12.7
71	Lu	175	97.412–97.40	D, G	97.412	57COL1		97.4
		176	2.60–2.588		2.588			2.6
72	Hf	174	0.199–0.163	D	0.16	56WHI1		0.2
		176	5.23–5.15		5.21			5.2
		177	18.56–18.39		18.56			18.5
		178	27.23–27.08		27.10			27.1
		179	13.78–13.73		13.75			13.8
		180	35.44–35.07		35.22			35.2
73	Ta	180	0.0123–0.0117	X	0.0123	56WHI1		0.012
		181	99.988–99.9877		99.9877			99.988
74	W	180	0.16–0.1164	D	0.13	48WHI1		0.1
		182	26.554–26.09		26.31			26.3
		183	14.43–14.24		14.28			14.3
		184	30.68–30.63		30.64			30.7
		186	28.85–28.38		28.64			28.6
75	Re	185		U	37.398	73GRA1	NBS-SRM 989	37.40
		187			62.602			62.60
76	Os	184	0.018	D, G	0.02	37NIE1		0.02
		186	1.67–1.59		1.59			1.58
		187	1.67–1.61		1.64			1.6
		188	13.27–13.15		13.27			13.3
		189	16.21–16.08		16.14			16.1
		190	26.42–26.15		26.38			26.4
		192	41.21–40.96		40.96			41.0
77	Ir	191		X	37.3	54BAL1		37.3
		193			62.7			62.7
78	Pt	190		X	0.01	56WHI1		0.01
		192			0.79			0.79
		194			32.90			32.9
		195			33.80			33.8
		196			25.30			25.3
		198			7.20			7.2
79	Au	197			100			100
80	Hg	196	0.156–0.147	D	0.15	55DIB1		0.2
		198	10.12–10.02		10.12			10.1
		199	17.01–16.83		16.98			16.9
		200	23.21–23.07		23.07			23.1
		201	13.27–13.12		13.26			13.2
		202	29.81–29.64		29.64			29.7
		204	6.85–6.69		6.78			6.8
81	Tl	203	30.07–29.08	D	29.46	48WHI1		29.5
		205	70.92–69.93		70.54			70.5

TABLE OF ISOTOPIC COMPOSITIONS OF THE ELEMENTS AS DETERMINED BY MASS SPECTROMETRY (*cont.*)

Atomic No.	Element	Mass No.	Range of published values	Notes	Best measurement† from a single natural source	Ref.	Reference material (see appendix)	Interim isotopic composition for average properties
82	Pb	204	1.65–1.04	R, G	1.4245	68CAT1	NBS-SRM 981	1.4
		206	27.46–20.97		24.1447			24.1
		207	23.57–17.62		22.0827			22.1
		208	54.33–51.28		52.3481			52.4
83	Bi	209			100			100
84	Po							
85	At							
86	Rn							
87	Fr							
88	Ra							
89	Ac							
90	Th	232			100			100
91	Pa							
92	U	234	0.0058–0.0050	R, G	0.0054	71SHI2	NBS-SRM's	0.005
		235	0.7246–0.7131		0.7200		U005-U980	0.720
		238	99.2818–99.2699		99.2746			99.275
93	Np	237						

†In some cases the values have been adjusted to satisfy the constraint that the sum of the individual compositions be equal to 100%.

APPENDIX

Sources of reference materials

I.A.E.A. Samples such as smow, slop, slac, nbs-RS-1 and 1a may be obtained from: International Atomic Energy Agency, Section of Hydrology, Vienna I, Körntner Rin Austria.

SVEC Professor Svec has offered to make available aliquots of a very pure natural lithium sample. Samples may be obtained from: Professor H. J. Svec, Department Chemistry, Iowa State University, Ames, IA 50010, USA.

NBS-SRM's NBS Standard Reference Materials may be purchased through: Office of Standard Reference Materials, National Bureau of Standards, B311 Chemist Building, Washington, DC 20234, USA.

EEC-GEEL Standards may be obtained through: Chief, Central Bureau for Nuclear Measurements, European Economic Community, Geel, Belgium.

NBS-RS (Reference Samples) Samples may be obtained through: Chief, Analytical Spectrometry Section, National Bureau of Standards, A25 Physics Buildin Washington, DC 20234, U.S.A.

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composition determines the atomic weights to adequate precision.

(3) *The atomic weight of the element in a standard reference material.* The atomic weight of the element in question in a standard reference material is a precisely determinable number. However, as soon as the material is divided difficult experimental problems arise concerning statistically adequate numbers and homogeneity. The definition of atomic weight for every element in the Table would then become a difficult experimental task.

(4) *The atomic weight of a specific mineral (possibly in a definite geological occurrence) of proven homogeneity.* This alternative presents some of the same difficulties, as those encountered with the previous alternative, though to a lesser degree.

These alternatives were already clearly outlined at the Madrid meeting. Speakers preferred the second alternative, that of carefully chosen isotopic compositions, as the basis for the Standard Atomic Weights to be tabulated. One reason for this preference is that many elemental properties, of increasing importance, are characteristic of the isotopic composition rather than of the atomic weight alone (though for mono- and di-nuclidic elements the one determines the other uniquely).

In summary, the Commission proposes the following tentative definition:

An atomic weight of an element is "the ratio of the average mass per atom of an element to 1/12 of the mass of an atom of nuclide ^{12}C".

The Commission also tentatively proposes that, after 1977, it should publish biennially a Table of Standard Atomic Weights defined by isotopic composition and consistent with that atomic weight that in the judgment of the Commission is most probably encountered by chemists.

LABELLING OF WELL CHARACTERIZED MATERIALS

In its 1973 Report the Commission pointed out that a large variety of materials in commerce now contain elements having an isotopic composition other than "normal". Some manufacturers and users would favor the introduction of precise statements on labels so worded as to minimize misunderstandings and errors in the interpretation of analytical data or inadvertent use of valuable isotopically enriched materials for common purposes. The Commission tentatively proposed possible wordings for such labels, and called for comments from the chemical public and from experts who had been alerted to this

increasing problem. Some respondents considered such problems outside their interests and of marginal importance to chemical trade, but the majority were favorably inclined to the Commission proposing an appropriate wording for labels of well characterized materials.

In proceeding to recommend the introduction of such a standardized form of labelling this Commission wants it to be understood that the common practice of quoting atomic or molecular weights on bottles has by no means outlived its usefulness. Nevertheless, it is also true that such labelling in many instances would leave important ambiguities, due to departure from stoichiometry or due to the presence of more than two isotopes of constituent elements. In any event, such labelling only rarely is based on measurement on the sample. The quoting of molecular weights computed from the IUPAC Table of Atomic Weights could in some cases be misleading, for example, for lithium compounds many of which are now prepared from residues of an undisclosed isotope separation process. The situation is less critical for compounds of hydrogen. Whereas tons of water depleted of HDO are discharged, the chance of this water in undiluted form re-entering inadvertently a chemical preparatory laboratory is in the absence of unusual circumstances, considered to be negligible.

The Commission thus recommends that the manufacturers of well characterized materials should themselves judge whether additional labelling is advisable in any specific case to avoid possible misconceptions or errors by the user or simply to reassure the user of the "normality" of the material. If this type of labelling is used one of the following kinds of statements is recommended by the Commission for use:

(1) Atomic weights conform with values published in the IUPAC Table of Atomic Weights. (It might be considered desirable, though not essential, to include the date of the IUPAC Table referred to.)

(2) The actual atomic weight of element(s) .... in this particular sample is (are) .... (In this statement "atomic weight(s)" could be replaced by "isotopic composition(s)".)

(3) Element X is enriched (depleted) in isotope ^{y}X.

In some materials statement (1) can be applied to some elements and statement (2) can be made for one or more other elements in the same sample. Probable error limits would often be helpful in statement (2), and also in statement (3) when it is combined with quantitative data expressed as percentage enrichment (which itself should be defined).

The Commission has requested the widest possible dissemination of these proposals and welcomes comments especially before its next meeting in 1977. Such comments and relative questions should be directed to the Commission's Secretary, Dr. N. E. Holden, Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

THE ISOTOPIC COMPOSITION OF THE ELEMENTS

Until 1973, the IUPAC Commission on Atomic Weights was concerned principally with dissemination of carefully evaluated and up-dated atomic weight values. At its meeting in Munich in that year the Commision, at the request of the IUPAC Inorganic Division, undertook to assemble, evaluate, and ultimately to disseminate data on the mass-spectrometrically determined isotopic compositions of the elements. For elements with three or more stable isotopes this information is more detailed than implied by quoting an atomic weight value. In other words, for such elements a given atomic weight within a range can be consistent with many isotopic compositions. It should also be emphasized that the atomic weight value calculated on the basis of the best evaluated mass-spectrometrically determined isotopic composition for a given element may not necessarily agree with the best atomic weight value derived from all significant published measurements by all methods.

The Commission accepted this important new task and the IUPAC Mass Spectrometric Evaluation Group (IMSEG) was formed within the Atomic Weights Commission. That Group has made much progress in the intervening two years and has produced an interim version of the "Table of Isotopic Compositions of the Elements as Determined by Mass Spectrometry". This Table is here reproduced with minor changes agreed upon during the 1975 Commission meetings. The Table constitutes the first internationally evaluated and selected compilation of data on the isotopic composition of the elements. It is based on a more fully documented report to be published independently by its authors. As mentioned above, however, the interim values when converted to atomic weights will not always be absolutely consistent with the 1975 Table of Atomic Weights.

At the 1975 meetings of IUPAC and its constituent bodies in Madrid, IMSEG was reconstituted as the Subcommittee for the Assessment of Isotopic Composition (SAIC) within the Commission on Atomic Weights. The functions of SAIC are wider than were those of IMSEG as the new Subcommission is concerned not only with mass-spectrometric but with all measurements for deriving isotopic compositions.

When in 1977 and future years the Commission, publishes tables of critically evaluated isotopic compositions based on work done within SAIC, the values will be made consistent with the Table of Atomic Weights. Thus, for example, if a purely chemical determination is judged to be by far the most reliable, then the corresponding atomic weight will be used as a constraint in the assignment of isotopic abundances. In many cases, of course, the mass-spectrometric and purely chemical or other data will be of comparable reliability, necessitating correspondingly more complex procedures for arriving at the best values.

Present members of SAIC are P. de Bièvre (*Chairman*), I. L. Barnes, A. E. Cameron, R. Hagemann, N. E. Holden and H. Thode.

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

For many years the Commission on Atomic Weights has included in its Reports tables of relative atomic masses of selected nuclides and half-lives of some radionuclides, although it has no prime responsibility for the dissemination of such values, No attempt has, therefore, been made to state these values at the greatest precision or to make them any more complete than is needed to enable users to calculate the atomic weights of materials of given abnormal or changing isotopic composition.

The extension of the Commission's Report to include evaluated data on isotopic composition for normal materials (see preceding section) has rendered the separate tabulation of relative atomic mass data for stable nuclides largely superfluous. In future years the

TABLE OF RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

Name	Symbol	Atomic number	Mass number	Relative atomic mass	Half-life†	
Technetium	Tc	43	97	96.906	2.6×10^6	a
			99	98.906	2.13×10^5	a
Promethium	Pm	61	145	144.913	18	a
			147	146.915	2.62	a
Polonium	Po	84	208	207.981	2.90	a
			209	208.982	102	a
			210	209.983	138.38	d
Astatine	At	85	209	208.986	5.4	h
			210	209.987	8.1	h
			211	210.987	7.21	h
Radon	Rn	86	211	210.991	15	h
			222	222.018	3.824	d
Francium	Fr	87	212	211.996	19.3	m
			222	222.018	15	m
			223	223.020	22	m
Radium	Ra	88	226	226.025	1600	a
			228	228.031	5.75	a
Actinium	Ac	89	225	225.023	10.0	d
			227	227.028	21.77	a
Thorium	Th	90	230	230.033	7.7×10^4	a
			232	232.038	1.40×10^{10}	a
Protactinium	Pa	91	230	230.035	17.4	d
			231	231.036	3.25×10^4	a
			233	233.040	27.0	d
Uranium	U	92	233	233.040	1.59×10^5	a
			234	234.041	2.44×10^5	a
			235	235.044	7.0×10^8	a
			236	236.046	2.342×10^7	a
			238	238.051	4.47×10^9	a
Neptunium	Np	93	236	236.047	1.3×10^6	a
			237	237.048	2.14×10^6	a
Plutonium	Pu	94	238	238.050	87.8	a
			239	239.052	2.41×10^4	a
			240	240.054	6.54×10^3	a
			241	241.057	14.7	a
			242	242.059	3.87×10^5	a
			244	244.064	8.3×10^7	a
Americium	Am	95	241	241.057	4.32×10^2	a
			243	243.061	7.37×10^3	a
Curium	Cm	96	242	242.059	163	d
			243	243.061	28	a
			244	244.063	18.1	a
			245	245.066	8.5×10^3	a
			246	246.067	4.76×10^3	a
			247	247.070	1.54×10^7	a
			248	248.072	3.5×10^5	a
			250	250.078	1.1×10^4	a
Berkelium	Bk	97	247	247.070	1.4×10^3	a
			249	249.075	3.2×10^2	d
Californium	Cf	98	248	248.072	3.3×10^2	d
			249	249.075	3.51×10^2	a
			251	251.080	9.0×10^2	a
			252	252.082	2.64	a
			254	254.087	6×10	d
Einsteinium	Es	99	253	253.085	20.47	d
			254	254.088	276	d
Fermium	Fm	100	255	255.090	20.1	h
			257	257.095	100.5	d

†a = year; d = day; h = hour; m = minute.

Commission intends to tabulate the relative atomic masses within the isotopic composition tables. For this reason it has now also decided to revert to the policy of its 1969[6] and earlier Reports in which the selection for a separate table of relative nuclidic masses was made from radionuclides only.

In this year's Table of relative atomic masses of selected radionuclides the values are those recommended by A. H. Wapstra and the half-lives were provided by N. E. Holden. In general, the values are consistent with Wapstra and Gove,[3] and Holden and Walker[44] respectively.

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